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Microclimate regimes following gap formation in a montane secondary forest of eastern Liaoning Province, China

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Abstract: In order to improve the understanding of the role of a canopy opening/gap on the physical environments in a secondary forest in Northeastern China, a case study was conducted in and around a small irregular gap in a montane secondary forest. The secondary forest, which was severely disturbed by human beings about 50 years ago, was dominated by *Quercus mongolica* and *Fraxinus rhynchophyllaan*. Temporal variation in photosynthetic photon flux density (PPFD), air temperature (T_A) at 10 cm above the ground, soil temperature (T_S) and soil water content (SWC) at top-layer (0−15 cm) and sub-layer (15−30 cm) were measured from May to September after the second year since the formation of the small gap (the ratios of gap diameter to stand height were less than 0.5) in 2006 respectively. Results indicated that the highest value of PPFD occurred at the northern edge of the gap, particularly at the beginning of the growing season in May. On sunny days, the highest value of PPFD appeared earlier than that on overcast days. Maximum and mean values of T_A were higher in the northern part of the gap, and the minimum values of T_A were at the southern edge of the gap. Soil temperature varied obviously in the gap with the range from 1 to 8 ºC. Maximum values of T_S occurred at the northern part of the gap, which was significantly correlated with the maximum values of T_A (R = 0.735, P<0.05). SWC was higher in the top-layer (0−15 cm) than that in sub-layer (15−30 cm), but the difference of them was not significant (p>0.05), which might be attributed to the small gap size and the effects of aboveground vegetations. From these results, the maximum of PPFD in the study area occurred at the northern part of the gap, which was consistent with the results observed in north hemisphere, but the occurrence time varied with the differences of the latitudes. The highest values of air and soil temperatures also occurred in the northern part of the gap because they were affected by the radiation. However, the variation of temperature in July was different from other months due to the influence of gap size. And the values of soil water content were neither higher in the gap in the wet season nor lower in the dry season, which might be affected by the gap size and topography the gap located. The variations of light, soil and air temperatures, and soil moisture in this small irregular gap might be related to the effects of the micro-site, which affects the regeneration of plant species.

Keywords: Forest gap; Microclimate; PPFD; Temperature; Soil moisture

Introduction

Many studies have reported that forest structures affected the dynamics of vegetation and forest successions (Guo *et al.* 1998; Chen 1999; Ren *et al.* 2001; Ding and Song 2004; Blanco *et al.* 2006; Kariukia *et al.* 2006; Chapman *et al.* 2006; Zhu *et al.* 2006). These studies focused on the relationship between forest structure and vegetation dynamics, but microclimatic conditions were paid a little attention (Liu *et al.* 2000; Wang *et al.* 2002; Catherine *et al.* 2005; Heithecker *et al.* 2006). Microclimates play an important role in the ecological processes of forest ecosystems, which impacted on other factors such as nutrient release, decomposition and circle, etc. (Zang *et al.* 1998; Liang *et al.* 2001; Wang *et al.* 2002; Clinton 2003; Ritter *et al.* 2005). Variations of all these parameters and their complex correlations have strong effects on forest development state.

Forest gap has been studied for many years as a small scale disturbance (Li *et al.* 1997; Xia *et al.* 1997; Zang *et al.* 1998; McCarthy 2001). It strongly influenced forest dynamics and succession (Runkle 1990; Xia *et al.* 1997; Zang *et al.* 1998; McCarthy 2001; Wang *et al.* 2006). Microclimates in and around the forest gap changed immediately after the gap formation. First of all, the light changes strongly, then, the higher solar radiation increases the air temperature and decreases the air humidity (Gray *et al.* 1997; Liu *et al.* 2000; Xiang *et al.* 2002; Härdtle *et al.* 2003; Ritter *et al.* 2005). The changes of microclimates due to gap formation also affected the available moisture of soil. Some reported results show that it is wetter in gaps in wet season and drier in dry season (Ricklefs 1977; Sha *et al.* 1999; Liu *et al.* 2000; McCarthy 2001; Wang *et al.* 2002; Zhang *et al.* 2003). However, the manifold and often contrary results reported from gap studies indicate that it is difficult to make generalizations.

Temporal and spatial variations of microclimates in forest gaps have been observed in different forest ecosystems in China (Liu *et al.* 2000；Wang *et al.* 2002; Zhang *et al.* 2003), but these

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studies were mostly carried out in Southern China, and a few were conducted in montane regions of northeastern China. The secondary forests in this region occupy a large area. Small gaps, i.e., the ratios of gap diameter to stand height were less than 0.5 (Zhu *et al.* 2003), in these secondary forest systems are very common. Considering the effects of microclimates on forest dynamics and ecological processes, it is necessary and significant to conduct the studies about forest gaps in this area.

The aim of this study was to describe temporal and spatial variations of microclimates including PPFD, air temperature, soil temperature and soil moisture in and around a small forest gap in a montane secondary forest. We hypothesized that the light level, soil and air temperatures would increase after the gap formation in the center of forest gap. Additionally, we expected the value of soil moisture would be higher in wet season and lower in dry season in the gap as mentioned by other studies.

Materials and methods

Site description

The observations were carried out in the experimental forests at Qingyuan Experimental Station of Forest Ecology (QESFE), Institute of Applied Ecology, Chinese Academic of Sciences. QESFE was located in the montane region of eastern Liaoning Province, China (41º51.102′ N，124º54.543′ E). The elevation is between 456–1116 m. The representative plants belong to Changbai flora. The secondary forests are dominated by *Quercus mongolica* and *Fraxinus rhynchophylla* at intermediate elevations (600–900 m). The climatic conditions are characterized by warmer summer and colder winter, which belongs to temperate and humidity region. The annual mean temperature is 4.7ºC, the maximum and minimum temperatures are 36.5ºC and -37.6ºC respectively. Annual mean precipitation is 810.9 mm and rainfall is occurring from June to August, the frost-free period is 130 days, and the time of vegetation growth is from April to September (Zhu *et al.* 2006).

One small gap was selected within 12 artificial gaps that were made by selective-cutting with index (which was defined by the ratio of gap diameter to stand height) 0.5, 1.0 and 1.5 in December 2004 (Zhu *et al.* 2003). Because small gaps were common in this area, the gap with index 0.5 (Fig. 1) was selected at the *Q. mongolica* and *F. rhynchophylla* ecotone near the intermediate elevation rage (about 700 m) (GPS, eTrex Summit, USA), which was set at the slope toward south and the gradient was 25º. The gap was irregularly shaped with different distances from the gap center to the gap edges. The equipment was set along two axes with the regular directions. The diameters were about 10 m in north-south and in east-west axes respectively. The trees were standing approximately 5 m from the gap center to the edges and the branches extended into the gap. The non-gap conditions were represented by the points in the forest stands nearby the gap.

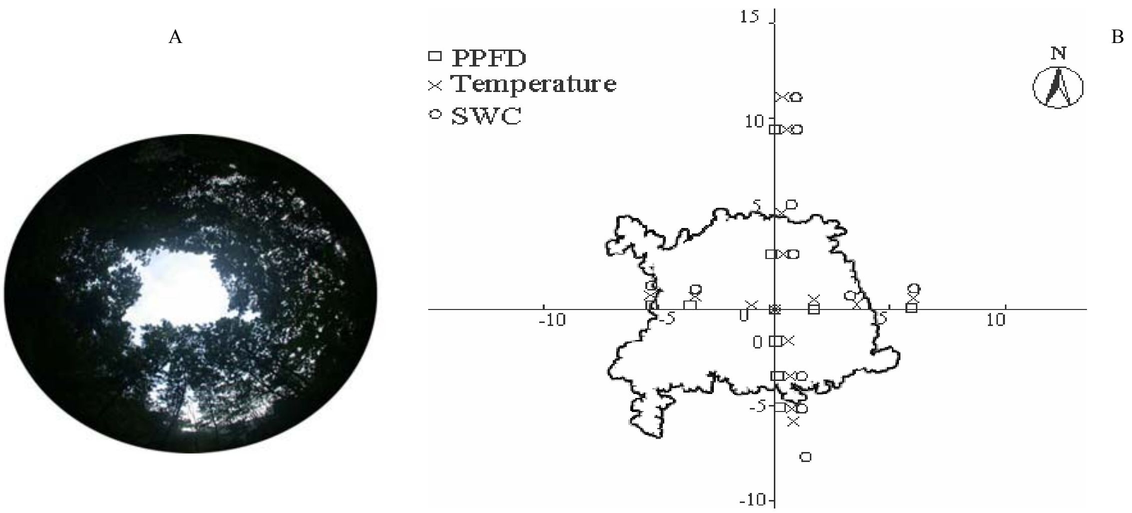

Fig. 1 Fisheye image of the small gap (A) and the points for measurements (B) in the small gap of the secondary forest

Microclimate measurements

Photosynthetic photon flux density

Photosynthetic Photon Flux Density (PPFD) was measured at 11 points along the two crossing transects (Fig. 1) from May 14 2006 to September 22, 2006. PPFD was defined as the photosynthetic photon flux density (μmol·m^{-2}·s^{-1}) in the 400–700 nm waveband. It was measured by LI-1400 system (LI-COR, Nebraska, USA) and light sensors with Watch Dog data logger (QMSW-SS, USA), which were set on the plate at 1.0 m height above soil surface in each point. PPFD was obtained by sampling at every one second, and the 10-min average was stored in a data logger (21x, Campbell Scientific, Utah, USA). The observations were conducted every month with two different weather conditions, i.e., sunny days and overcast days. The observation time was between 7:00–17:00 (GMT+8:00, the same hereafter) each day.

Air temperature and humidity

Onset HOBO H8 Pro Series logger (H08-032-08, MacArthur, USA) were set at a height of 0.1 m above the soil surface along the two transects to measure air temperature (T_A) and humidity. The data at 17 points were measured (Fig. 1). All loggers were put in the boxes preventing from rain and direct radiation. Temperature was sampled every 1 min and the 10-min average was logged automatically. The mean ($T_{A\ mean}$), maximum ($T_{A\,max}$) and minimum ($T_{A\,min}$) values of temperature each day were used for the analyses. The measurement time was between 7:00–17:00.

Soil temperature and moisture

Soil temperature was measured at 17 points by thermometer (Produced in Tianjin) (Fig. 1), which were placed at a depth of 5 cm under the soil surface along two transects. Every hour the data were read, and the maximum ($T_{S\ max}$), mean ($T_{S\ mean}$), minmum ($T_{S\ min}$) values of soil temperature were picked out. Volumetric soil water content was measured at different layers i.e., 0–15 cm and 15–30 cm along two transects (Fig. 1). The soil moisture was measured with TDR (TRIME-HD, Germany). 12 points were measured monthly with TDR at two layers from May to September. Three reduplicates were made in each layer. Under the canopy of the forest stands, light, temperature, and humidity were measured at 4 points respectively.

Statistics analyses

To test the differences of PPFD or temperature at different points, one way ANOVA with repeated measurements followed by Tukey multiple comparisons were applied to the following data: (i) mean integrated daily PPFD for each month; (ii) 10-min averages of PPFD for 2-h intervals on sunny days and overcast days; (iii) daily $T_{A\ max}$, $T_{A\ mean}$, $T_{A\ min}$, $T_{S\ max}$, $T_{S\ mean}$, $T_{S\ min}$ for each month; (iv) daily differences between $T_{S,\ max}$ and $T_{S\ min}$ for each month. Data on sunny days of each month were used as the repeated measurement.

The average daily integrated PPFD were transformed with log and tested by Tukey multiple comparisons. The relationship between T_S and T_A was established by Pearson correlation statistics. All statistical tests were conducted in SPSS software (SPSS 11.5), significant level was determined as $P<0.05$.

Results

Photosynthetic photon flux density

The data of sunny days and overcast days in each month were analyzed. The distribution of PPFD in the gap was generally much more variable through the day on the sunny days than that on the overcast days (Fig. 2). Between 6: 00 and 8: 00, the values of PPFD were very low on both sunny and overcast days, but they were higher on the sunny days after 8:00 than those on the overcast days, particularly the value of the point at the northern edge of the gap. The highest value of PPFD occurred during the periods of 10: 00–12: 00 on both sunny and overcast days.

Compared the values of PPFD along the south-north transact, some differences exhibited between sunny and overcast days. On overcast days, the values were close to each other at both northern and southern part of the gap before 10:00, but the highest value of PPFD occurred near the northern edge of the gap. On sunny days, the distribution of PPFD was always in a bell-inversed shape between 10:00-14:00, and the highest value was almost in the northern edge of the gap. The values along the east-west transact were also in bell-inversed shape on sunny days, but they varied more complicatedly on the overcast days than on the sunny days. The position of highest PPFD varied in different times. The average PPFD in September was higher than that in July, which might be affected by the weather condition. It always rains in July, so the value of PPFD was low.

Overall average PPFD (which was calculated by the daily value in every month) for each month was higher in the gap than that under forest canopy (Fig. 3). The average PPFD was the highest in May, which was significantly different from the values in July and September ($P<0.05$). For each point, the average PPFD from May to September was the highest in the gap center, which was different from the daily PPFD occurred at north to 3 m and 6 m, and was also significantly different from the gap edges at east to 6 m, west to 5.8 m and north to 9 m. The highest value of the whole growing season was in the center of the gap in May.

Air and soil temperature

During the measurement period, monthly $T_{A,\ mean}$ in the center of the gap, the gap edge and the forest stand was 18.82ºC, 18.68ºC and 18.67ºC, respectively. $T_{A\ max}$ in the gap center was 38.8ºC in July, and $T_{A\ min}$ was 10.6ºC in September. The difference between $T_{A\ max}$ and $T_{A\ min}$ did not vary greatly at all points in the forest stands, which ranged between 12ºC and 17ºC, but the differences in the gap center and at the gap edges varied at the range of 17–25ºC and 17–28ºC respectively (Fig. 4-a). This result indicated that there was a greater variation in the temperature at the gap edges and gap center. The average temperatures at different points in the gap were not significantly different with each other ($P>0.05$). The points with $T_{A\ max}$ were found in the north and east parts closed to the gap center (but not at the gap center), and $T_{A\ min}$ appeared at the west and south of the gap.

Soil surface temperatures in June and September were significantly different with those in July and August ($P<0.05$), and the monthly mean temperature in the gap center was 0.56 ℃ higher than those at other points. The temperatures of points were not significantly different with each other except points at the southern and northern edges of the gap ($P>0.05$). The maximum temperature of the point at the north gap edge was significantly different with other points ($P<0.05$), which was up to 27 ºC. The difference between $T_{S\ max}$ and $T_{S\ min}$ of all months was below 10ºC for all points, and the points with high temperature differences were at and around the gap center (Fig. 4-b).

The difference between T_A and T_S at the point at southern forest stand was significantly different from that at the northern part of the gap, and the value in July was significantly different with that in other months ($P<0.05$). By correlation analysis, $T_{A\ mean}$ and $T_{S,\ mean}$ were significantly correlated in all months ($R = 0.735$, $P<0.05$).

Soil moisture

The average values of soil water content for the two layers (0–15 cm, 15–30 cm) were 23.5% and 23.1% respectively during the growing season. The highest values of both layers were found in June in the gap (Fig 5), which in topsoil occurred at the gap center and that in subsoil occurred at the northern part of the gap. The points with the lowest value of SWC were different in each layer, which was 11.4% at the east edge of the gap at the surface and was 11.8% at the western edge of the gap at the deep layer. Compared SWC at different points, there were no significant differences between the two layers ($P>0.05$), except the values of the points between the gap center and eastern forest stand at surface layer and between the southern forest stand and gap center at deeper layer. SWC in forest stand, gap edge and gap center were no significant difference ($P > 0.05$), but the SWC in the gap center was the highest in months except in May. In July, the average SWC were much higher than those in other months.

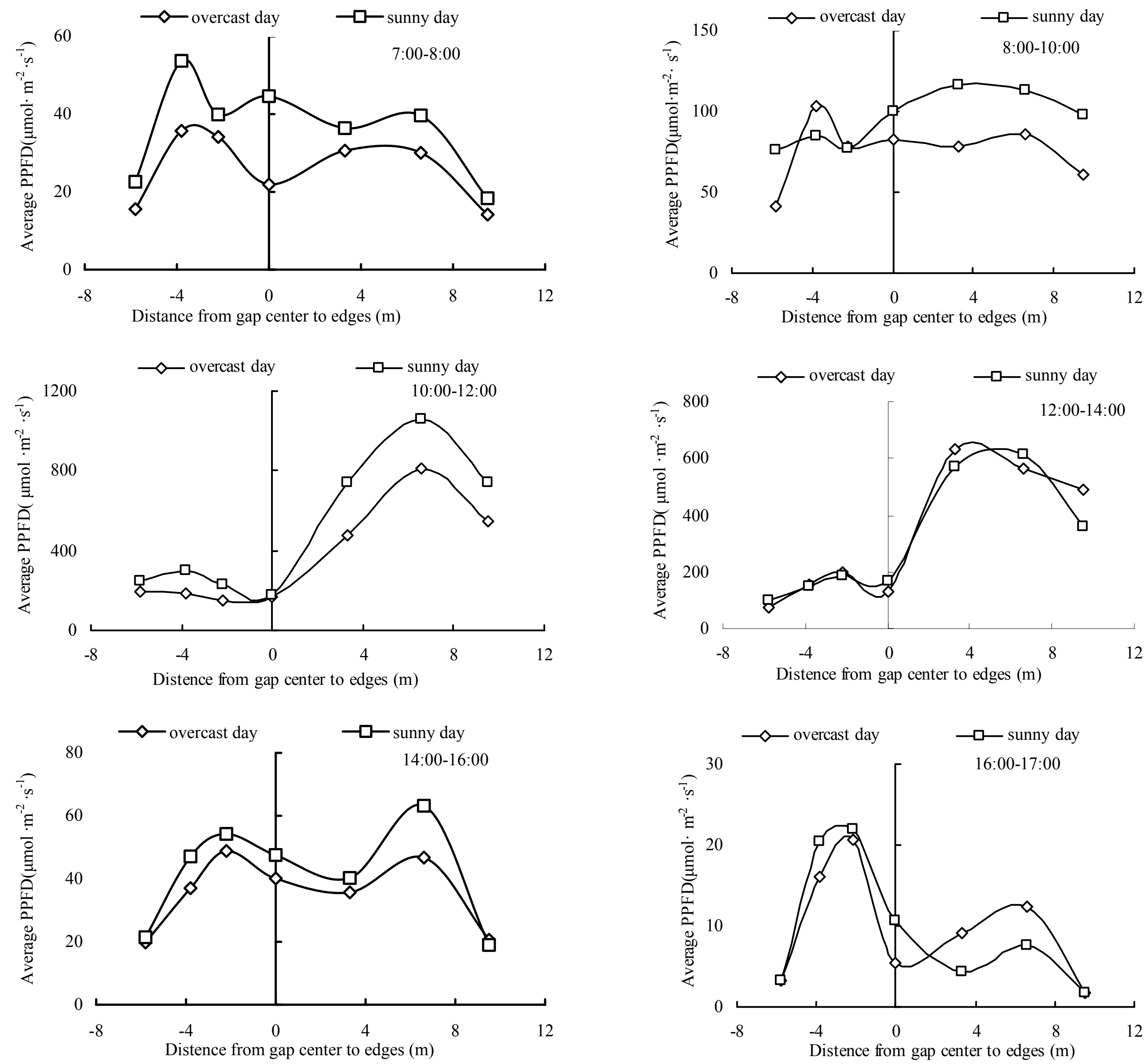

Fig. 2 Average photosynthetic photon flux density (PPFD: μmol·m^{-2}·s^{-1}) along the south-north (plus: north; minus: south. The same hereafter) on sunny (20 September) and overcast day (19 September) in 2006

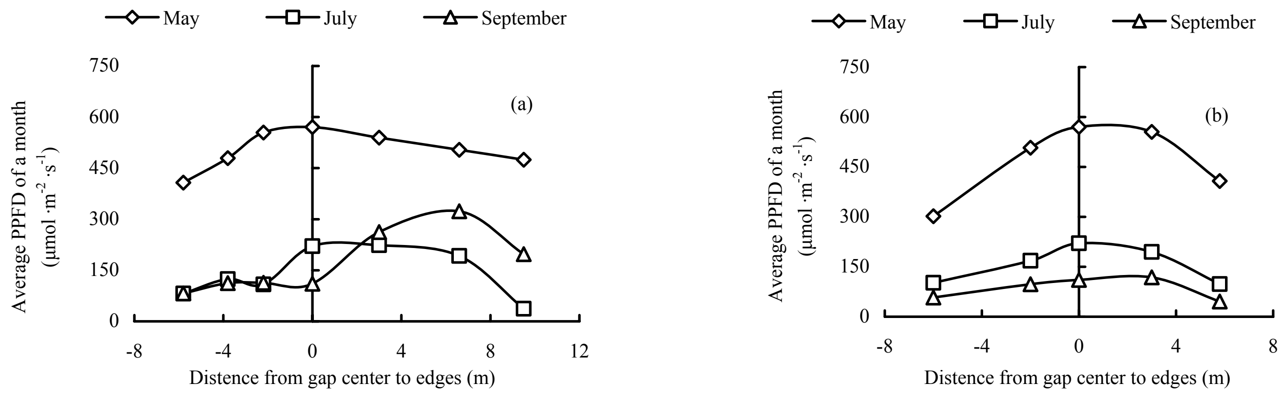

Fig. 3 Average PPFD in different positions along the south-north (a), east-west (b) (plus:west; minus: east. The same hereafter) in May, July and September

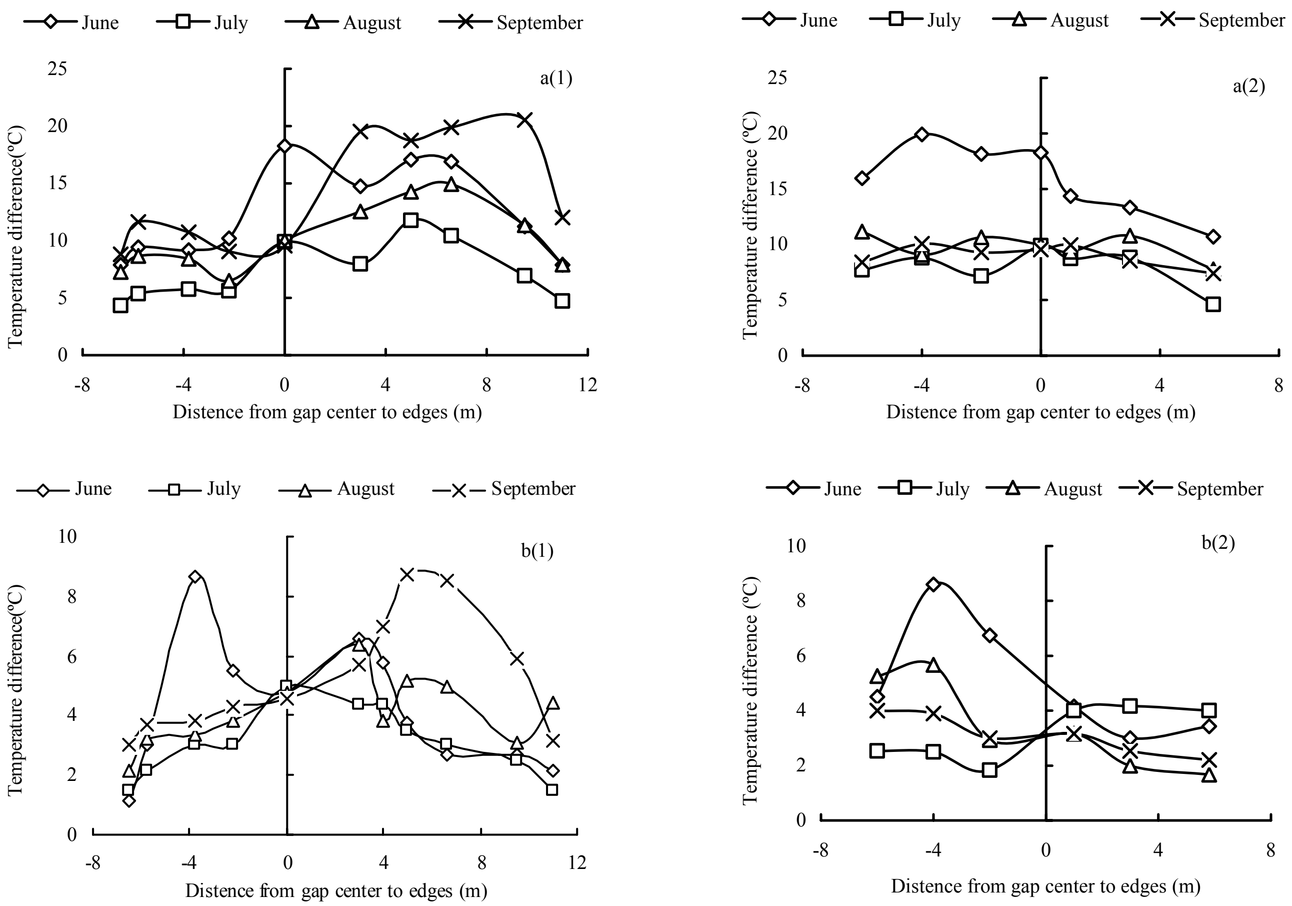

Fig. 4 Air temperature difference and soil temperature difference at different points along two transacts
a: air temperature difference; b: soil temperature difference; (1): along the south-north transect. (2): along the east-west transect.
Temperature difference= T_{max} - T_{min}

Discussion and conclusions

Microclimate conditions were strongly affected by gap size and gap shape (Gagnon *et al.* 2004; Bouchard *et al.* 2005; Heithecker *et al.* 2006). Gap size influenced solar radiation and air temperature in gaps with less than 600 m^2 in gap size (Ritter *et al.* 2005). Gap shape also affected the resource availability in and around the gap. The effects of gap size and shape on microclimates became more profound (Gagnon *et al.* 2004; Pritcharda *et al.* 2004), and the microclimates would change drastically (Poulson *et al.* 1989; McCarthy 2001; Pritchard *et al.* 2004; Ritter *et al.* 2005).

Lots of references proposed the conclusions that PPFD increased most in the northern part of the gap in northern hemisphere (Schaetzl *et al.* 1989; Wang *et al.* 2000; Zhang *et al.* 2001). Our results got the same conclusion, i.e., the highest value of PPFD occurred at the northern edge of the gap, especially on sunny days and at the beginning of growth season, which was not consistent with the result as we expected. On sunny days, PPFD was always up to the highest value between 10:00–12:00, which was earlier than that of southwestern of China (Wang *et al.* 2000). This difference might be due to the variation of the angle of sun in different latitudes and slope. The value of PPFD at northern edge of the gap was the highest, which might be affected by the location in northern hemisphere (Zhang *et al.* 2002) and the total time of solar radiation. Average PPFD was higher in May than that in other months, which could be explained by some reasons: (1) In this area it rains rarely and is always sunny days in May, but the rain is abundant from the end of June to the mid-August，so the number of sunny days in May was more than other months; (2) It might be concerned with the plant growth. Because it is time for plants to begin growing, especially the height growth, which may need a great proportion of total PPFD in May; (3) In May, there was much more PPFD reaching the gap before canopy closed. In addition, PPFD varied much more in the south-north transect than that in the east-west transect, which might be caused by the gap shape and latitude.

Both air and soil temperatures were in wider ranges at the gap edges. T_A varied not strongly in the forest stand, but acutely in the gap. $T_{A, max}$ and $T_{S, max}$ occurred at the northern part of the gap, and $T_{A,min}$ was in the western and southern edges, which was similar to the distribution of minimum PPFD. The maximum difference of air temperature occurred in the northern part of the gap in each month, which was in the gap center in June. The maximum difference of soil temperature also occurred in the northern part of the gap in all months, but it was in the southern part of the gap in June. Those results might be affected by solar radiation, and the temperature increased with the increasing of

solar radiation. The differences of air and soil temperatures along east-west transect varied strongly in June. The values of T_A subtracted T_S were not always positive, which might be affected by vegetation cover, ground layer and the transmission of heat (Zhang *et al.* 2003; Wang *et al.* 2002).

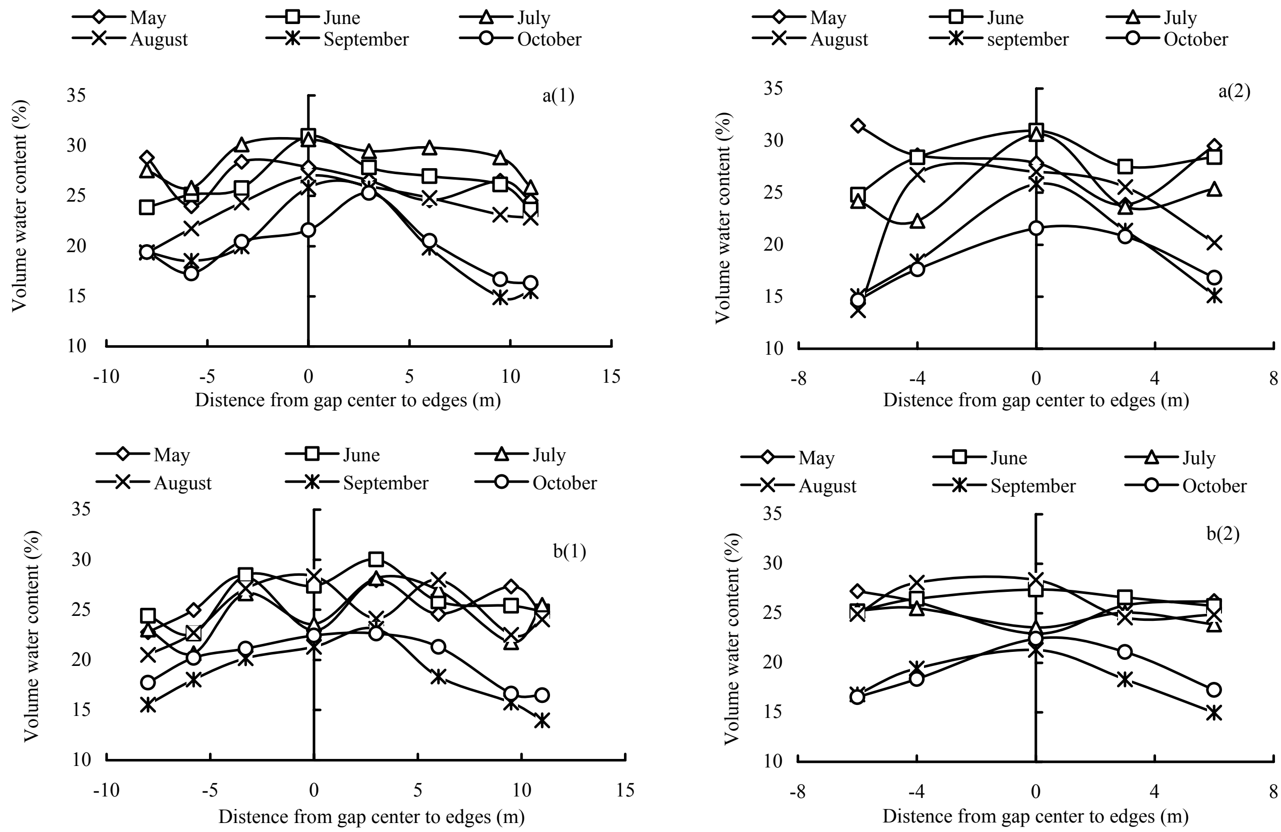

Fig. 5 Soil water content in different layers of all points along two transacts

a: topsoil layer; b: subsoil layer. (1): along the south-north transact; (2): along the east-west transact.

Some studies showed that soil moisture in the gap was wetter in the wet season and drier in the dry season in the forest stand respectively (Ricklefs 1977; Sha *et al.* 1999; Liu *et al.* 2000; McCarthy 2001; Wang *et al.* 2002; Zhang *et al.* 2003). Our results did not get the similar results. SWC was not significantly different among all months via our observation, but the SWC was higher in July than that in other months. Generally, SWC in topsoil was drier in dry season and wetter in wet season than that in subsoil (Wang *et al.* 2002), but there were not significantly different between them. These results may be caused by the small gap size, location and soil hydrological properties (Schaetzl *et al.* 1989; Gálhidy *et al.* 2006; Heinemann and Kitzberger 2006; Walters *et al.* 2006). The gap with small canopy openness could not get enough water when it rained (Li *et al.* 2005). The topographical factors would affect the soil water content, and this gap was located at the slope toward south and water always flowed away, so the soil water content in the gap would not be different from each other. Soil hydrological properties determined the hydraulic conductivity of soil, which could affect the spatial variability of water.

Through the data obtained only in one year, we could get that maximum PPFD in this area occurred at the northern part of the gap, which was consistent with the results observed in north hemisphere. However, the occurrence time varied with the difference of latitudes. The highest values of air and soil temperatures also occurred in the northern part of the gap because they were affected by the radiation. However, the variation of air and soil temperatures in July was different from other months. The values of soil water contents in the gap were neither higher in the wet season nor lower in the dry season and could be affected by the gap size and topography the gap located, which was not consistent with the reported results. The variations of light, soil and air temperatures, and soil moisture in this small irregular gap might be relative to the effects of the micro-site, which affects the regeneration of plant species. Due to the data observed just one growing season, further research and continuous observations still need to be done.

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